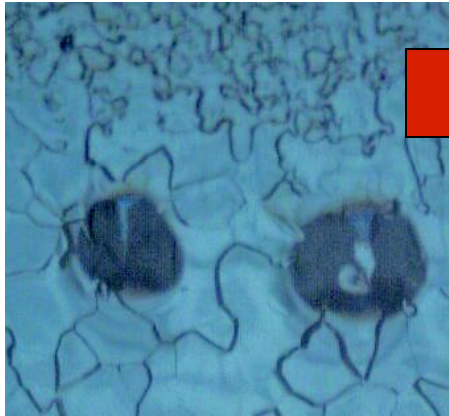


Success stories - From seed funds to DOE R&D Grants

A LABORATORY-UNIVERSITY COLLABORATION TO UNDERSTAND PERFORMANCE LIMITS OF SRF CAVITIES

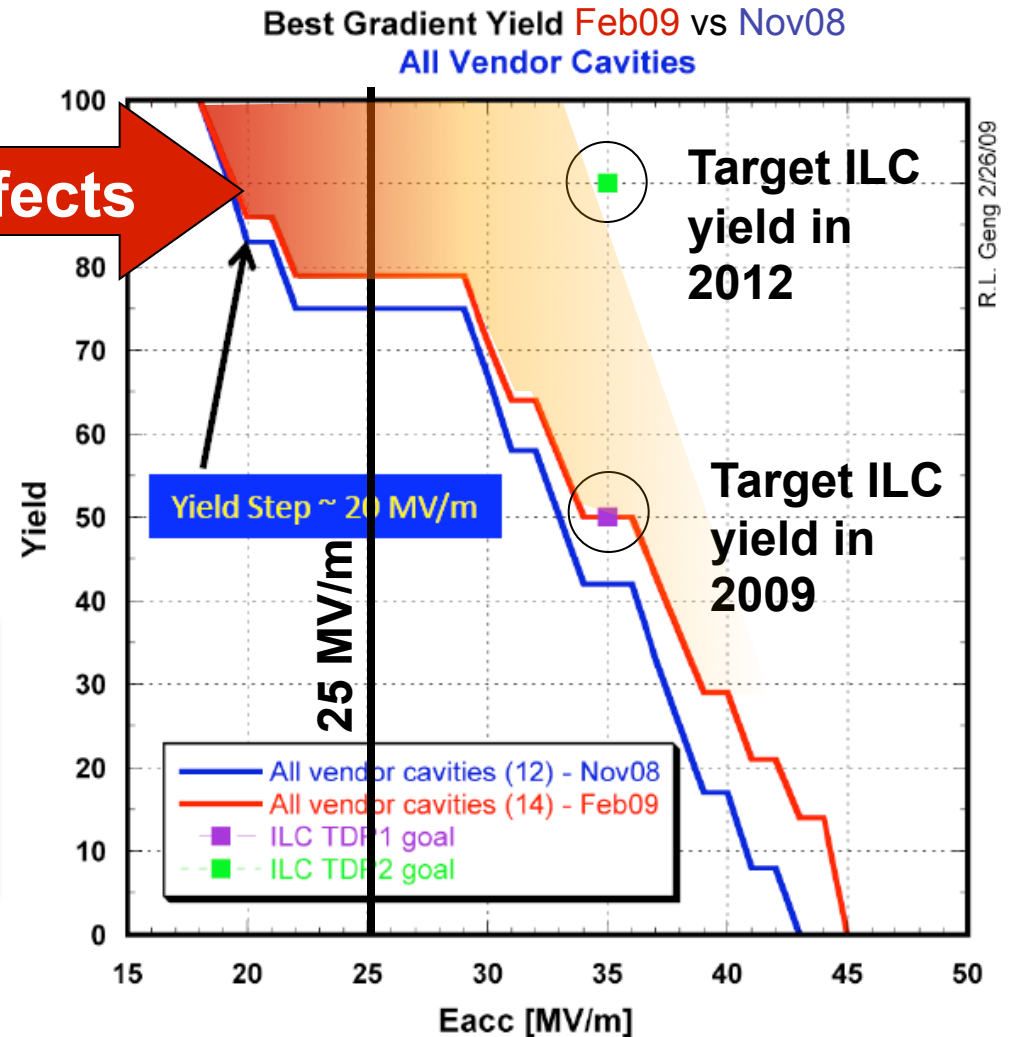
- FNAL, UChicago, Florida State, Northwestern, IIT
- \$1.5M / 3 years
- Theme 1: What are origins of weld pits and other gross defects?
 - Impact: prevention of the worst defects, improvement of processing yield
 - 3+ Year Impact: coherent understanding throughout entire forming-chemistry-baking process — perfect cavities??
- Theme 2: How do defects affect superconductivity?
 - Impact: understanding of what the optimum surface ought to be

Weld-pit problem is most urgent issue



Gross defects

Correlation between presence of large pits and quench is strong for poorly performing cavities



Approach

- FNAL – prepare test pieces by “standard” processes (or cut them out of cavities)
- UChicago – understand oxidative chemistry and surface state prior to chemistry or upon re-exposure to air
- Northwestern – provide details about the sub-surface distribution of oxygen, hydrogen, dislocations, etc.
- Florida State – Large-area imaging, topography, low-temperature measurements, and detail cut-out of regions of interest
- IIT – point contact tunneling into regions of interest

How the seed program set this up

- [2007](#): UChicago explores Nb exposure to “air of the day” and oxygen
- Result: Nb_2O_5 is *NOT* robust; Many defects present at 300K heal with baking or ion irradiation
- Implication (with IIT): *Magnetic* defects interfere with superconductivity
- SRF grant: understand *subtle* effects of oxidation, in particular defects in the oxide
- [2008](#): UChicago explores pit structure and surface chemistry
- Result: *Carbon*, evidence for *dislocation-assisted pitting*
- Implication: oxidation story must include dislocations, which also pile up at edge of weld HAZ
- SRF grant: understand how *material working* affects oxidation and downstream chemical processing

Seed program has also had broader impact

- Better realization by SRF programs that fundamental research in academia is vital for success
- Wider acknowledgment that processes occurring at the niobium surface are subtle and complex
 - Tweaking recipes is not a viable fix for ILC goals
- Demonstration that hand-off between different talented academic groups can generate rapid gains in knowledge

Fundamental Studies of the Interfacial Chemical Kinetics and Morphological Evolution of Niobium During Oxidation

Steven J. Sibener, Univ. of Chicago

**The James Franck Institute and Department of Chemistry
& Lance Cooley, FNAL**

Nb & Related Oxides: Technical and Single Crystal Studies

- **Single Crystals & Technical Materials: Nb, Welds, ALD Coatings**
- **Chemical Evolution and Communication with Selvedge/Bulk**
- **Structural Evolution**
- **Baking and Cooldown After Annealing - *What is Going On?***
 - **Chemical Environment During Reactions: O, O₂, H₂O, H₂**
- **Synergistic Effects: electrons, photons, local electric fields**
- **Field Emission and Local Work Function**
- **Oxide Interactions with the Underlying Metal**

- ***Next: Extended Partnership and Capabilities via DOE-HEP Funding***

Robert R. Wilson on Superconductivity

"Between the fixed-target experiments that can be made with the highest luminosities, and the colliding-beam experiments that will reach the highest energies, we can anticipate a leap forward in our knowledge of particles and forces - **all through the magic of superconductivity.**"

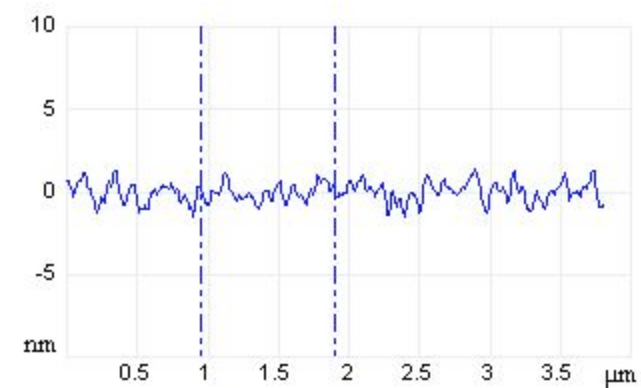
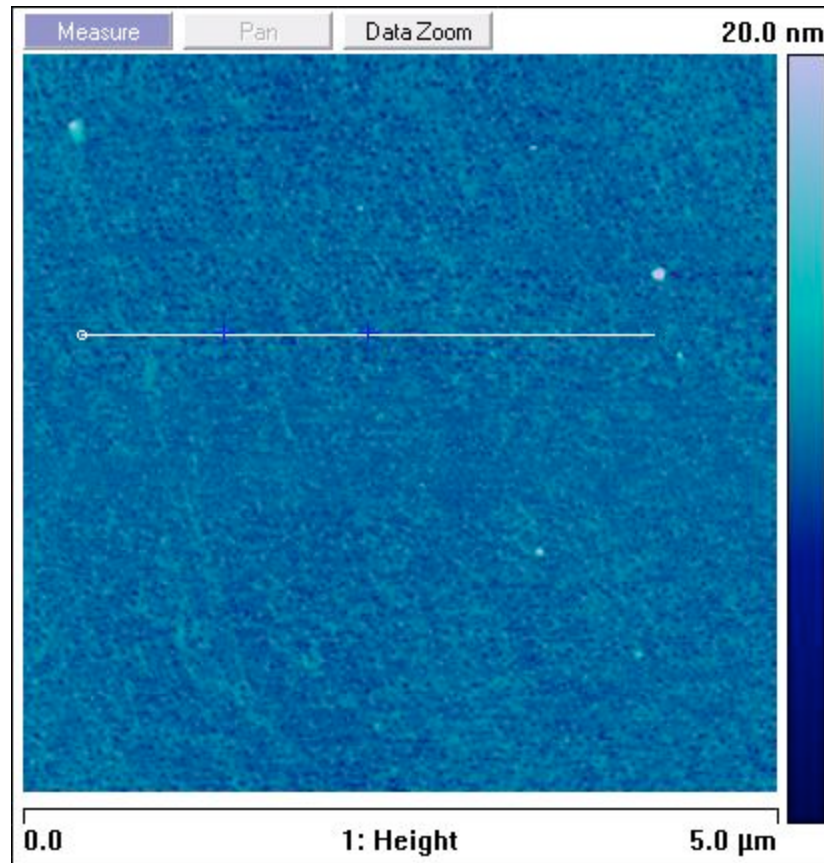
(*Fermilab - Physics, The Frontier and Megascience*, p. 196, Lillian Hoddeson, Adrienne W. Kolb and Catherine Westfall, Chicago and London: The University of Chicago Press, 2008.)

N.B. Improved Surface & Materials Chemistry Needed to Extend This Vision to the Future - Higher Fields! Fundamental Understanding of Nb Surface Metallurgy Critical to this Goal

Why Do Subtle Changes in SRF Cavity Treatments Produce Profound Changes in Performance?

- Niobium cavities (melting point 2000 °C) – a bake at 150°C for a few hours can transform a *good* cavity into an ILC-qualifier or even a record-setter – why??
 - Any changes must be subtle
 - Any changes must happen at the surface
 - Oxygen is the most likely actor
- The Sibener Group brings its great expertise in surface and interfacial chemistry, including a detailed understanding of the atomic-level aspects of metallic oxidation

5-micron View of Weld-free Nb Polished at Cabot Micro. Atomic Force Microscopy Image of As-Received Sample



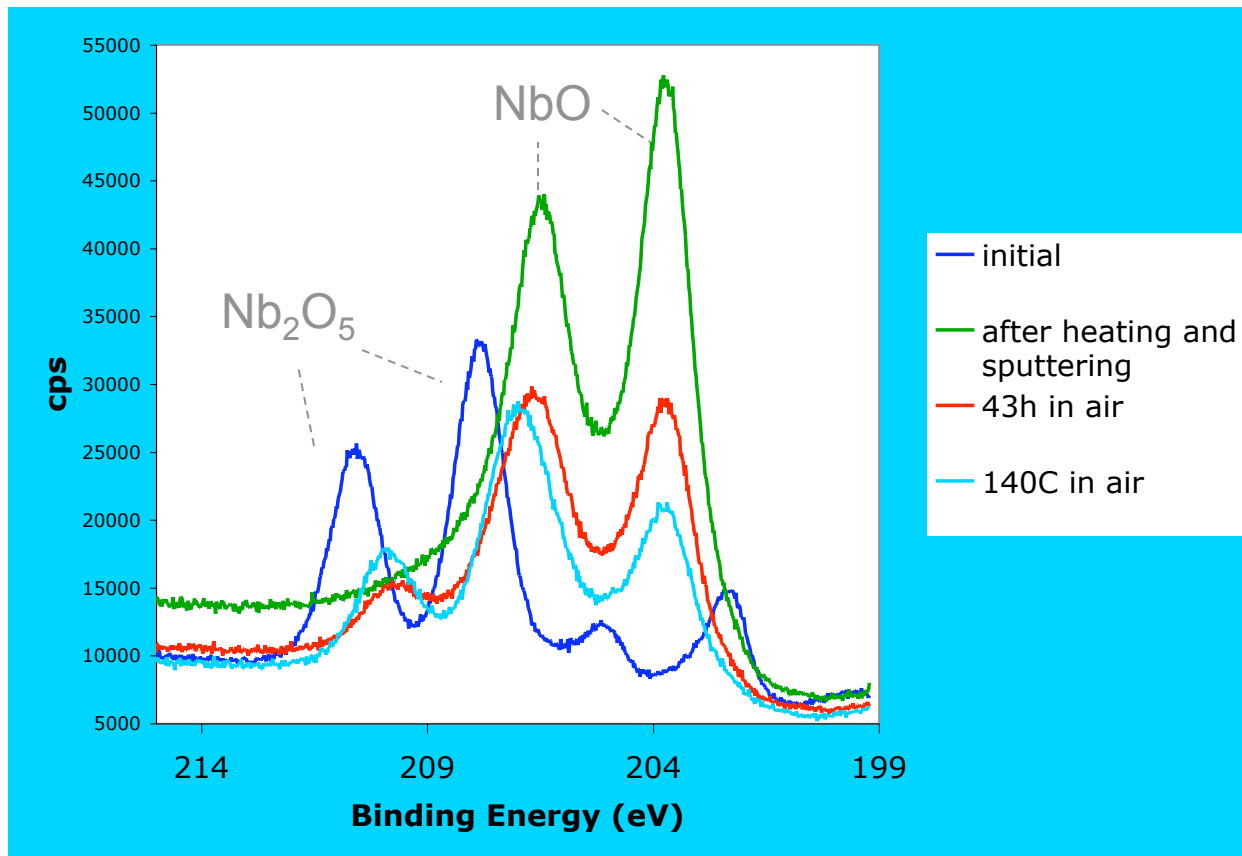
Average roughness is <0.5 nm

Imaging: Nataliya Yufa, Graduate Student at UChicago

Heating in Air and Aging: “Air of the Day”

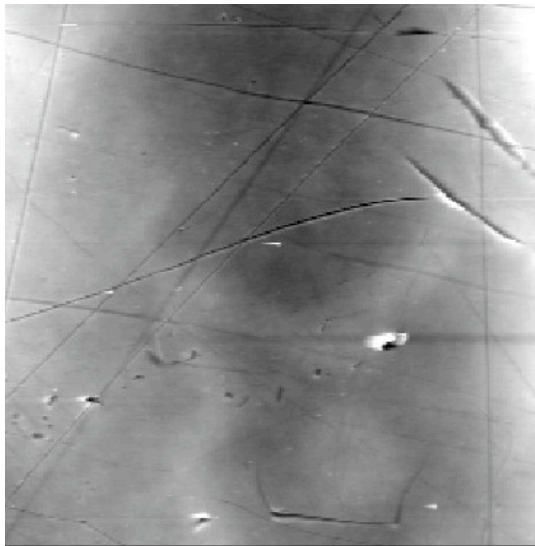
Typical Treatment: 1 hr at 140 C

- Nb 3d peaks show that more of the Nb are converting from NbO to higher oxides; O being **added** to sample (in UHV, oxygen tends to be subtracted from the surface and move into niobium metal)

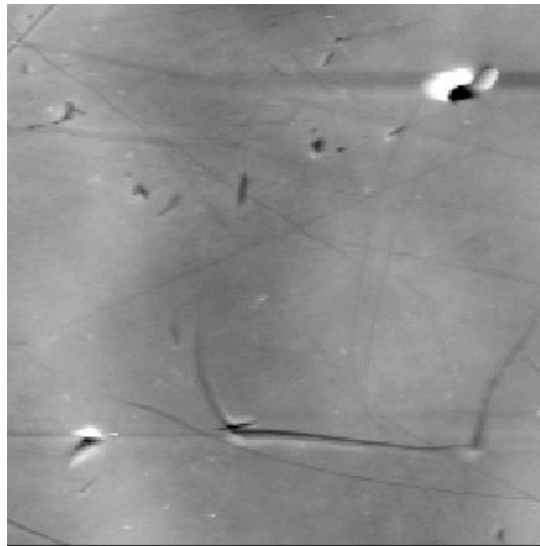


Atomic Force Microscopy of Sample w/ Welds

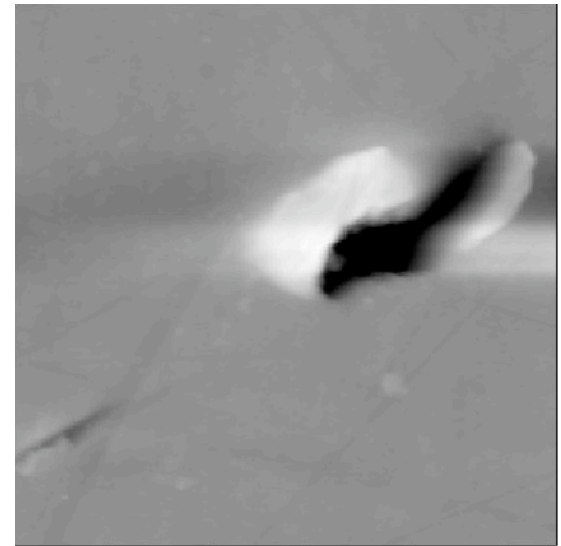
- Polished side of large sample
 - many scratches seen as well as a few pits



50 x 50 μm^2



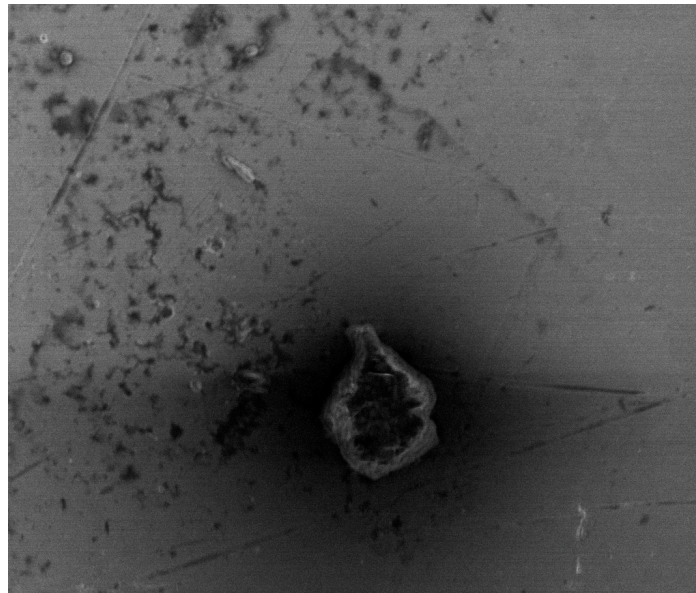
25 x 25 μm^2



5.75 x 5.75 μm^2

Scanning Electron Microscopy of Sample with Welds

- Polished side of larger sample
- N.B. One area was observed with lots of pits and a large pit which seems to cause charging (black area)



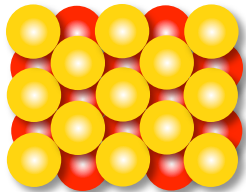
20 μm

Niobium Single Crystals

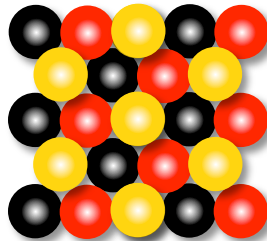
Nb(110), Nb(111) and Nb(100)



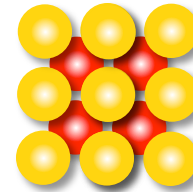
Nb(110)



Nb(111)



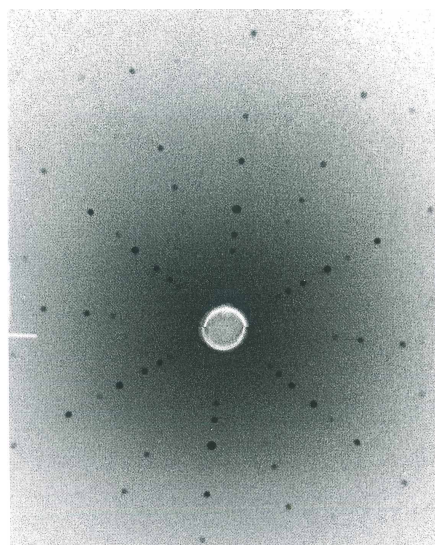
Nb(100)



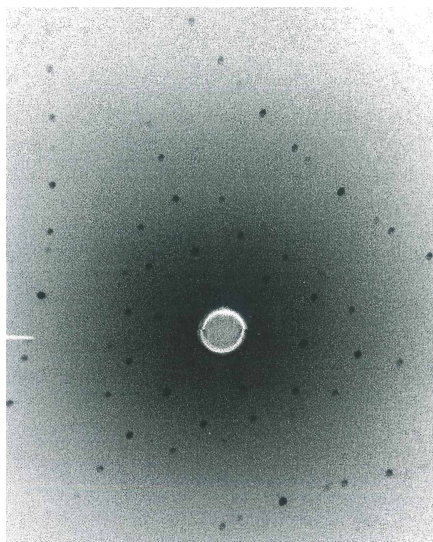
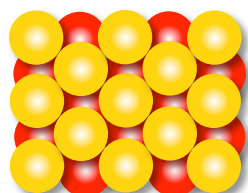
- Three crystal faces, material 99.99% purity
- Polished to $\sim 0.1^\circ$ of crystallographic orientation
- Final polish 0.05 microns
- Source: Surface Preparation Lab, Zaadam, The Netherlands

● = top layer Nb
● = second layer Nb
● = third layer Nb

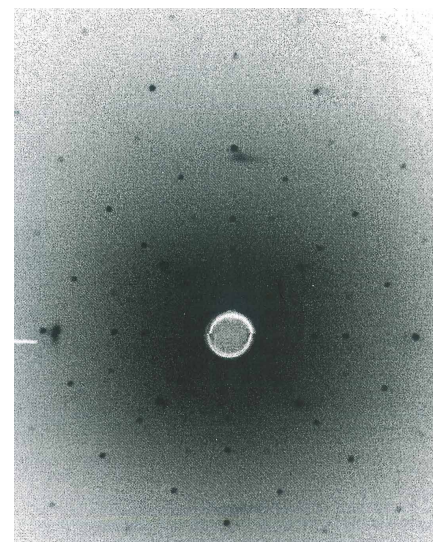
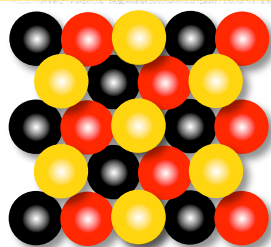
Laue X-ray Patterns Confirm Precision of Surface Orientation



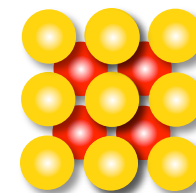
Nb(110)






Nb(111)



Nb(100)



-  = top layer Nb
-  = second layer Nb
-  = third layer Nb

UC-FNAL Seed Program: Fundamental Studies of the Interfacial Chemical Kinetics and Morphological Evolution of Niobium During Oxidation

Steven J. Sibener (UChicago) & Lance Cooley (FNAL)

Summary:

- Seed Grant Program Launched New UC-FNAL Collaboration
- 2-Year Seed Effort Helped Define Critical Issues
- Exploration of Fundamental and Technical Issues

Outcome:

Extended Partnerships & Capabilities with DOE-HEP Funding

The Expanded Team:

FNAL, UChicago, Florida State, IIT, Northwestern